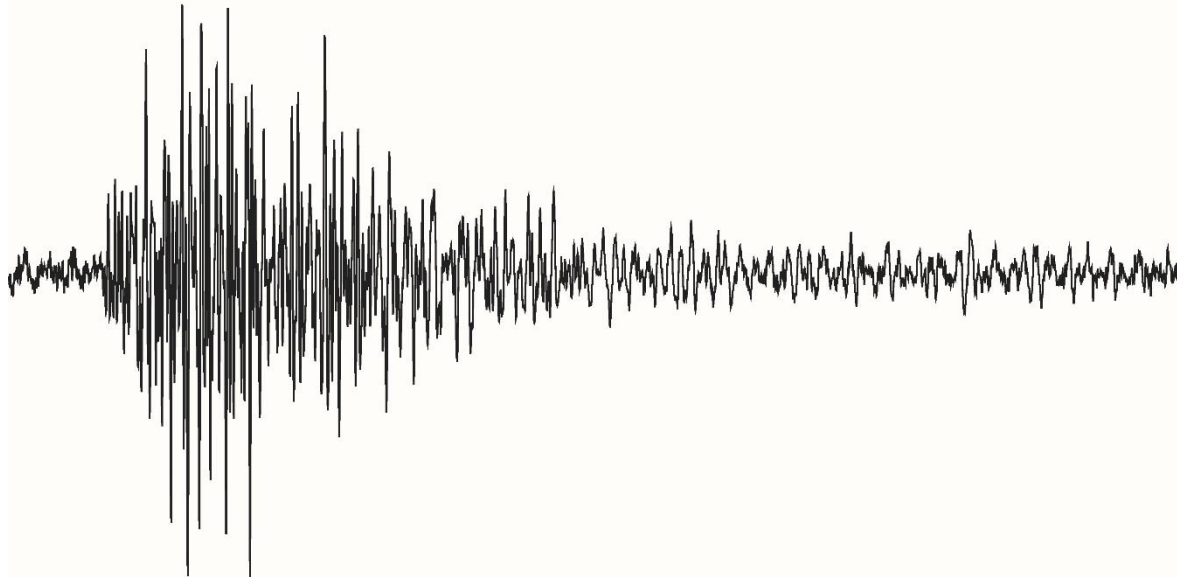


Installing your TC1 Processing Earthquake Data With AmaSeis and WinQuake Networking With Other Schools



By Linda and Ted Channel

and

Dr Caroline Neuberg



Foreword

There are around 500,000 earthquakes each year. 100,000 of these can actually be felt. The largest earthquake ever recorded was a magnitude 9.5 (Mw) in Chile on May 22, 1960. The world's deadliest recorded earthquake occurred in 1556 in central China. It struck a region where most people lived in caves carved from soft rock. These dwellings collapsed during the earthquake, killing an estimated 830,000 people. The normal average is 33 earthquakes of magnitude 5 and above per 7 days.

Scientists use seismometers (sometimes also called seismographs) to record the Earth's vibrations generated by tectonic earthquakes, volcanic eruptions, and other seismic sources such as nuclear tests. From these recordings, earth structure can be inferred and tectonic plate boundaries mapped. The holy grail of seismologists, finding a method to predict earthquakes and eventually saving lives, is still way out of reach of any legitimate and competent scientist.

Owning a TC1, a vertical component seismometer, is an exciting way to be involved in such a scientific adventure. This manual intends to assist you setting up your new instruments and answer as many questions regarding the setup as possible.

For the last 5 years in Fulneck School, Leeds, UK, I have enjoyed using a seismometer as a teaching and learning tool. Teaching with a seismometer generated lots of interest in my students, opening up my classroom to the world. I also like to believe that such an interest helps spark in them motivation for a scientific career.

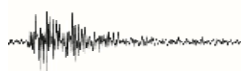
Have fun with your TC1!

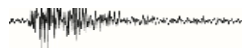
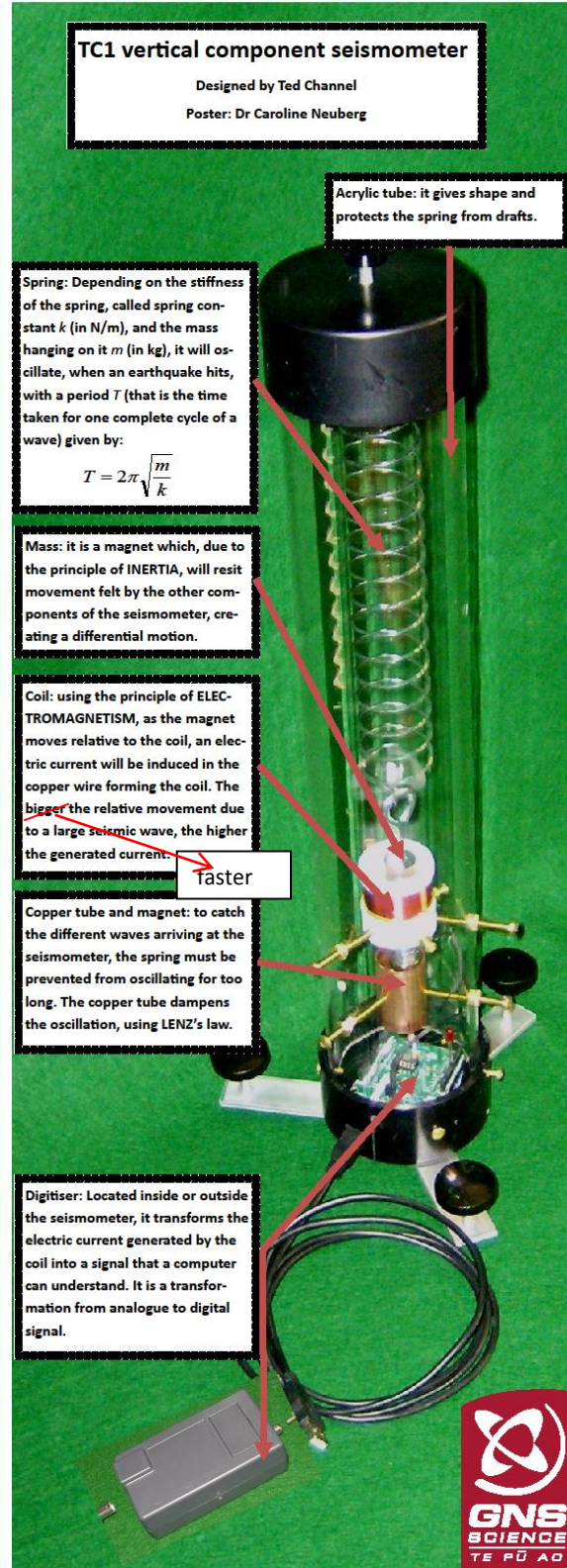
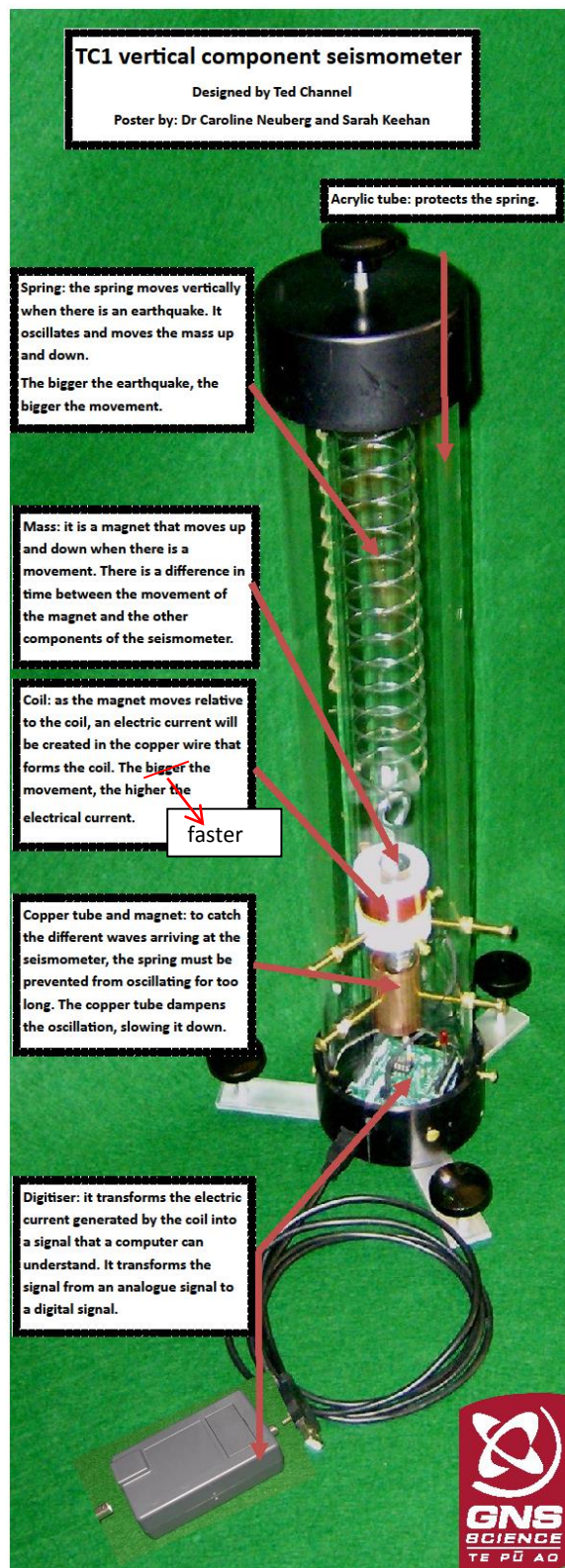
Dr Caroline Neuberg



Contents

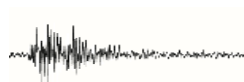
Step 1. Assembly instructions for TC1	5
Step 2. Downloading softwares	9
A) Arduino	9
1) For windows Vista, 7, XP.....	9
2) For windows 8 and 8.1.....	10
B) AmaSeis.....	11
C) Winquake.....	11
Step 3. Acquiring data and processing earthquakes.....	13
A) Adjusting the time.....	13
B) Setting up AmaSeis.....	14
C) Which earthquake have you recorded? Let's process the data.....	15
1) Receive USGS earthquake notification	16
2) Process the data.....	17
i. Extract the earthquake using Amaseis.....	17
ii. Identify the earthquake using WinQuake.....	19
Step 4. Networking with other schools using IRIS.....	24
Step 5. Problems? Where to turn for help?.....	28
Appendix A. Saving SAC binary file; time correction.....	29
Appendix B. Teaching geophysics with a vertical component seismometer ..	32





Step 1. Assembly instructions for TC1

		This is what your TC1 will look like once assembled. Remove sensor components from cardboard box. Remove top ABS cap containing spring.
		Hook eyebolt containing magnets over bottom of spring. Insert and lower the magnet assembly into top opening of acrylic tube. Ensure ABS cap sits snugly on the tube, but do not force it or damage tube. Position magnet assembly inside white coil and copper damper.





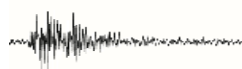
Top of magnet assembly should be even with top of white coil body. Heights are set before shipping, but if correction is needed, turn magnets and nuts up or down.

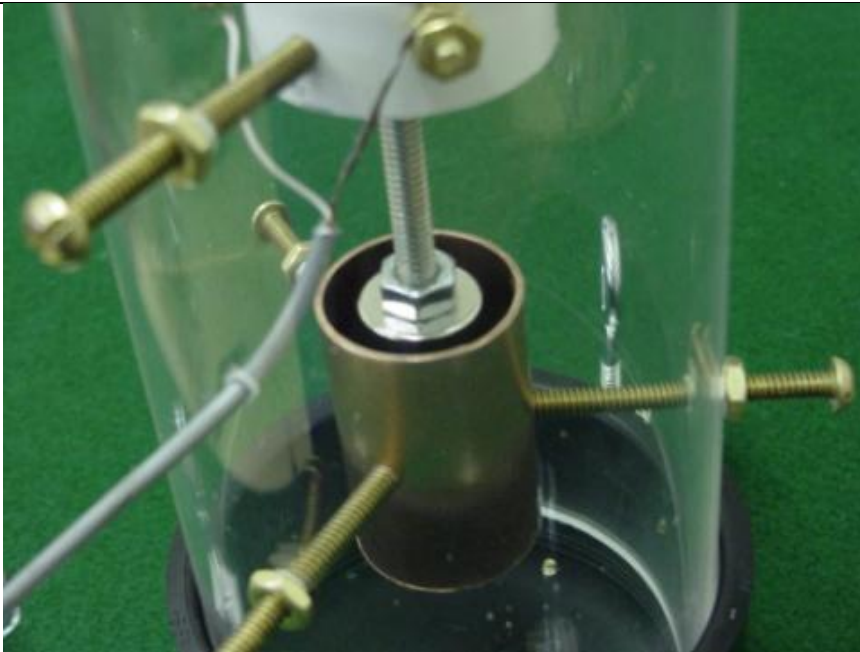


From a side view raise or lower the slinky spring, using the knob on the top cap, to make the coil magnets even with the top of the white coil.



From a top view, center the coil magnets, like a bull eye into the white coil body, leaving an even air space all around, with nothing touching the white coil. Do this using the three black base leg knobs or base screw.



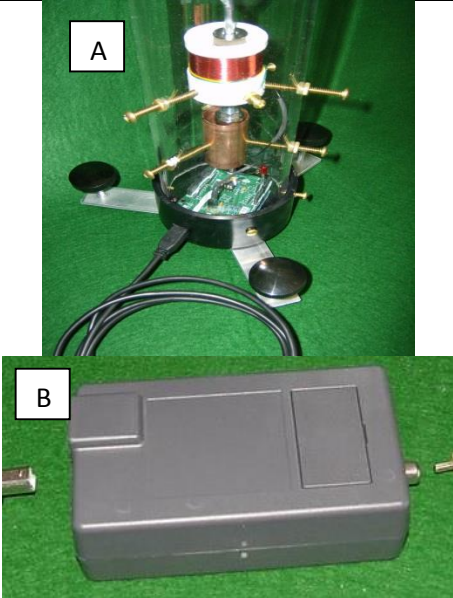


Repeat the same centering process with the copper damper tube and magnet. Damper magnet height should be about even with the top of copper damper tube. Again the heights are set before shipping, but if correction is needed, turn magnets and nuts up or down.



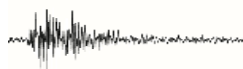
Use three adjusting legs on base to center magnets like a bulls eye inside coil and damper, with equal free space all around. Magnets must not touch inner walls or the sensor will appear to be working but will never record an earthquake. Periodically, ensure everything is still centered. NOTE: On the side of the black base is a small brass screw, used for shipping. Back this screw off and rotate the clear tube about 1". Finger tighten (only) this screw against the clear tube to make for a tighter fit



	between the clear tube and the black base. Spring can stretch or turn over time, so corrections may be needed.
	Depending on the TC1 version that you have, the NERdaq and Arduino Uno board are either integrated inside the TC1 (A) or in an independent grey box (B). Plug the sensor's NERdaq amplifier USB cable from NERdaq amplifier into a computer.
	Finding the correct place for your TC1. The most important factor is a GOOD ground coupling. A table is not a good idea. You may also want your students to see it, but not knock it over.

Using a hand held GPS or SatNav system, or Google Earth (press CTRL+L, Latitude and Longitude are displayed at the bottom of the screen), find the precise latitude and longitude of your station. You will need it for AmaSeis and Winquake. It needs to be expressed in decimal places so to convert your position data from degree, minutes, seconds into decimal, use for example the following program:

<http://www.directionsmag.com/site/latlong-converter/>



South and West are written as negative values, whilst North and East are positive.

Step 2. Downloading softwares

To acquire and process data, you will need to upload three softwares: Arduino, AmaSeis and Winquake. Depending on operating system, the programs to download will be located in slightly different web places. **At this stage, the seismometer is plugged in the computer.**

A) Arduino

As the digitalisation of the analogue signal is done via an Arduino Uno microcontroller board, you need this software such that your computer can read the signal. The program size is about 250 Mb.

Access the page <http://arduino.cc/en/Guide/Windows>

1) For Windows Vista, 7, XP

Access the page <http://arduino.cc/en/Guide/Windows>

Scroll to point 2:

2 | Download the Arduino environment

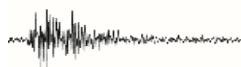
Get the latest version from the [download page](#).

Click on download page. Scroll to Arduino 1.0.5

Click on Windows Installer and select Run. Agree to the terms and conditions, then click next, then Install.

You then need to install the Arduino driver. Follow the subsequent instructions (not as daunting as it looks, promise!)

- Plug in your board and wait for Windows to begin its driver installation process. After a few moments, the process will fail, despite its best efforts
- Click on the Start Menu, and open up the Control Panel.
- While in the Control Panel, navigate to System and Security. Next, click on System. Once the System window is up, open the Device Manager.
- Look under Ports (COM & LPT). You should see an open port named "Arduino UNO (COMxx)"
- Right click on the "Arduino UNO (COMxx)" port and choose the "Update Driver Software" option. PLEASE MAKE A NOTE OF THE NUMBER XX WRITTEN AFTER THE COM.



- Next, choose the "Browse my computer for Driver software" option.
- Finally, navigate to and select the driver file named "arduino.inf", located in the "Drivers" folder of the Arduino Software download (not the "FTDI USB Drivers" sub-directory).
- Windows will finish up the driver installation from there.

2) For Windows 8 and 8.1

Arduino drivers have been updated to add support for Windows 8.1. The version to download is version 1.0.5-r2 located under the title: Arduino 1.5.6-r2 BETA (with support for Arduino Yún and Arduino Due boards).

Access the page <http://arduino.cc/en/Guide/Windows>

Scroll to point 2:

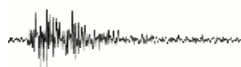
2 | **Download the Arduino environment**

Get the latest version from the [download page](#).

Click on download page. Scroll to Arduino 1.5.6-r2 BETA. Click on Windows Installer and select Run. Agree to the terms and conditions, then click next, then Install.

You then need to install the Arduino driver. Follow the subsequent instructions (not as daunting as it looks, promise!)

- Plug in your board and wait for Windows to begin its driver installation process. After a few moments, the process will fail, despite its best efforts
- Open up the Control Panel, by selecting "Settings" in the "Charm" list
- Select the section "Device and printers" and the option "Device manager", accept the changes on the pop up window.
- Look under Ports (COM & LPT). You should see an open port named "Arduino UNO (COMxx)"
- Right click on the "Arduino UNO (COMxx)" port and choose the "Update Driver Software" option. PLEASE MAKE A NOTE OF THE NUMBER XX WRITTEN AFTER THE COM.
- Next, choose the "Browse my computer for Driver software" option.
- Finally, navigate to and select the driver file named "arduino.inf", located in the "Drivers" folder of the Arduino Software download (not the "FTDI USB Drivers" sub-directory).
- Windows will finish up the driver installation from there.



B) AmaSeis

AmaSeis is the datalogger. It is the software that displays the ongoing activity recorded by the TC1. With Amaseis, you will be able to visualise the seismic activity as well as select, extract and save “earthquakes” files.

Access it at <http://pods.binghamton.edu/~ajones/AmaSeis.html>

Click on : Fetch **Version 3.2 Level 2012.07.06** here: [AmaSeisSetup.exe](#).

Follow the prompts from the Windows installation wizard.

C) Winquake

Winquake is the software that will allow you to analyse and process the earthquakes. It contains lots of necessary features such as filtering processes, event distance and magnitude calculations, calculation of P and S wave arrival times, and a link to Google Earth.

You need to decide whether your computer is running a 32 Bit or 64 Bit operating system.

To do so, check in Control Panel\System and Security\System.

Then access:

32-Bit:

http://www.seismicnet.com/software/wq336b_32bit.exe

64-Bit:

http://www.seismicnet.com/software/wq336b_64bit.exe

Run the installation and then follow the prompts from the Windows installation wizard, agreeing to the terms and conditions.

Select the desktop icon.

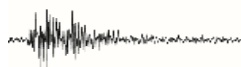
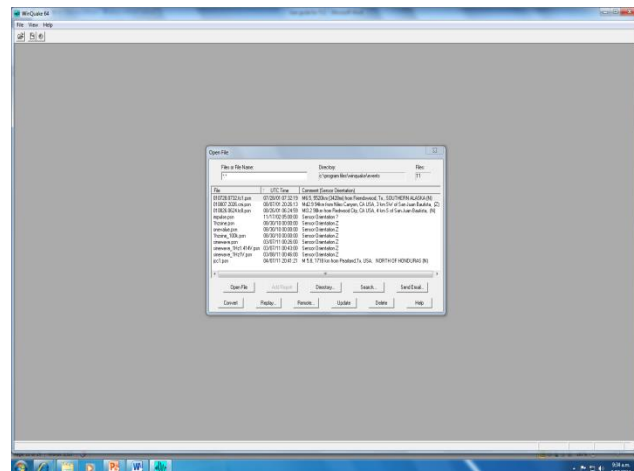
You are then asked to register, and asked to have the file.PSN associated with Winquake. Select yes to the last question. Winquake will open with the following screen:

Go immediately into File, on the left corner and select Register software.

Enter the registration:

Registration Name: New Zealand Schools

Registration Code: 22499



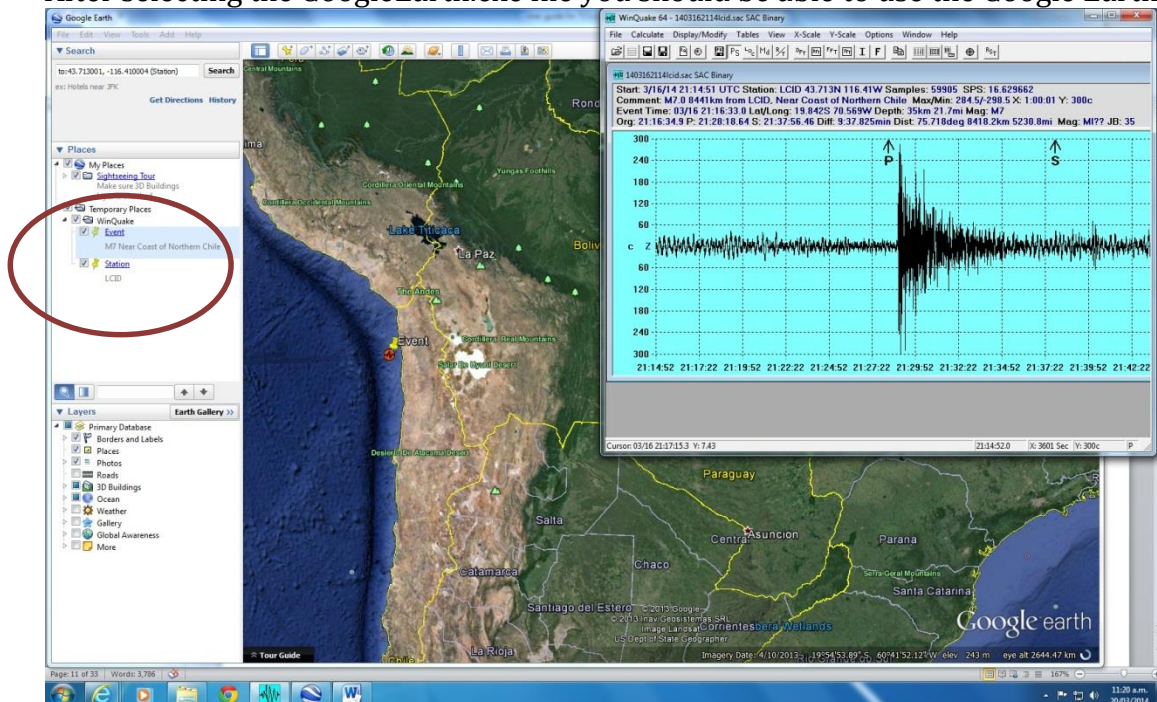
Close the registration window¹.

Using the Google Earth feature of Winquake program, you need to

- download Google Earth on the computer;
- In Winquake, under the "File" menu, you should see "Google Earth Exe". Select it. In the Locate Google Earth dialog box, locate the GoogleEarth.exe file. On most systems, it is located in this folder/directory:

c:\Program Files (x86)\Google\Google Earth\client\

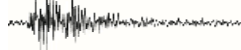
After selecting the GoogleEarth.exe file you should be able to use the Google Earth feature.



You are now (nearly!) ready to record seismic activity and process data!

Step 3. Acquiring data and processing earthquakes

¹If you experience registration issues, log into the computer as Administrator and turn off UAC. This page <http://windows.microsoft.com/en-us/windows-vista/turn-user-account-control-on-or-off> has information on how to disable it. Once you do that, you should be able to register WinQuake. Once you have it registered you can turn UAC back on again.



A) Adjusting the time

This is a very important step: you need to have correct computer time to be able to process earthquakes. The computer clock must be accurate within a few seconds, and an unaided computer cannot hold this tolerance. If your computer does not have an automatic time-setting and adjustment device (which it would have if your school has a network), use a device like an atomic clock, or an Internet program (an excellent resynchronize time : <http://www.pretentiousname.com/timesync/>).

You can adjust your computer time by clicking on the time on the right bottom corner of the screen; select change date and time settings; select the tab “Internet time” and let your computer adjust to the internet time.

Alternatively, you can download an atomic clock program from http://download.cnet.com/Atomic-Clock-Sync/3000-18512_4-14844.html Beware not to download the attached program (called Jotsey). Select the “Decline” option.

Before processing, note any clock error and write it down to be used later in WinQuake (Appendix A).

B) Setting up AmaSeis

Open AmaSeis: You may get an error, “Can’t open COM port”, and then another error. This is because we need to set up AmaSeis. NOTICE, IF YOU GET THIS ERROR AFTER YOU WERE SUCCESSFUL IN SETTING THINGS UP, IT MAYBE BECAUSE YOU HAVE ANOTHER AMASEIS RUNNING AND MINIMIZED ON THE TASK BAR. YOU CAN ONLY HAVE ONE AMASEIS OPEN.

Go to AmaSeis/settings/device, and select SEPuk1

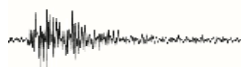
Go to AmaSeis/settings/COM port, and change it to the same com port as indicated in the device manager for the Arduino Uno hardware found. Please refer to Step2, Section A.

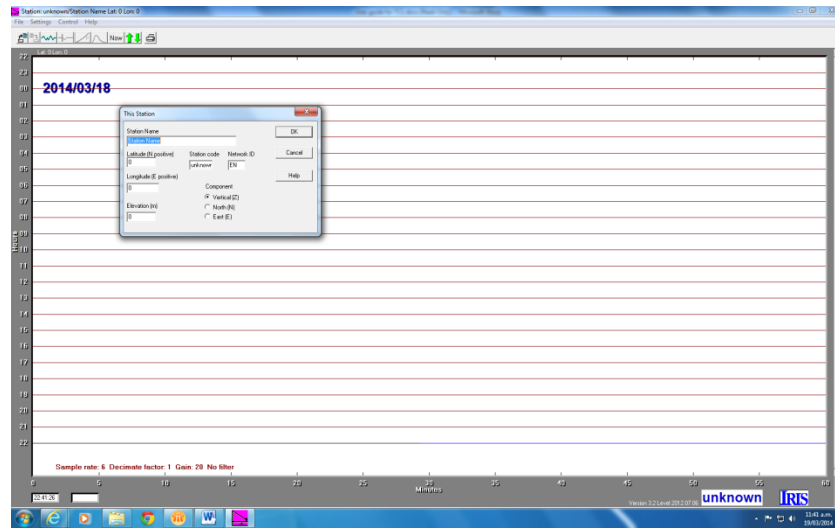
Close AmaSeis and reopen....hopefully you will get no error this time.

Go to Amaseis/settings/this station and enter the latitude, longitude, and elevation of your station.

Go to AmaSeis/settings/helicorder and change the gain to 4.

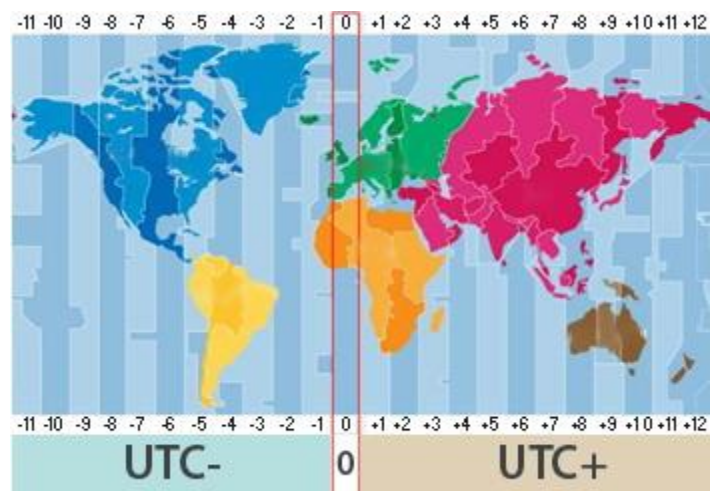
Go to AmaSeis/settings/show data values...in that window you should see a number flickering.





That's your data coming in. Leave this window open so you can monitor the numbers. Go to AmaSeis/settings/set zero level....change this number to about 32600. The objective here is to modify this set zero number to whatever brings the Black data line up or down to match and follow the Blue hour line on the helicorder screen. You can watch the flickering "show data values" window until it flickers close to zero. This maybe +10/-10.....or +100/-135, could be any numbers. Just keep changing the set zero level until the Black data line is following the Blue hour line on the screen.

You will realise that the time displayed on AmaSeis is UTC (**Coordinated Universal Time**; time standard used for many [Internet](http://www.timeanddate.com/worldclock/city.html?n=22) and [World Wide Web](http://www.timeanddate.com/worldclock/city.html?n=22) standards, as well as aviation). For New Zealand, **the time zone offset is UTC/GMT +13 hours or +12 hours** depending on daylight savings time. Check <http://www.timeanddate.com/worldclock/city.html?n=22> if you are uncertain.



That's it; you are now recording seismic activity!



c) Which earthquake have you recorded? Let's process the data

Now, the real fun begins.

Seeing a trace on the computer screen on AmaSeis, you will want to identify which earthquake you have recorded (the “who’s done it” aspect of the project). This is when you will use WinQuake.

However, you need to know where earthquakes happen (the suspects on the “who’s done it” list!). In New Zealand, the task is made more exciting by the fact that there are **teleseismic** events (distance station-epicenter >1000km) as well as many **local** events.

(picture <http://www.iris.edu/>)



For the local events, Geonet is the best source of information. For teleseismic events, IRIS seismic monitor (<http://www.iris.edu/seismon/>) is a good source, as well as USGS. You can get seismic alerts sent to your email/mobile as explained below.

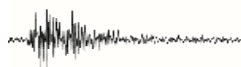
1) Receive USGS earthquake notifications.

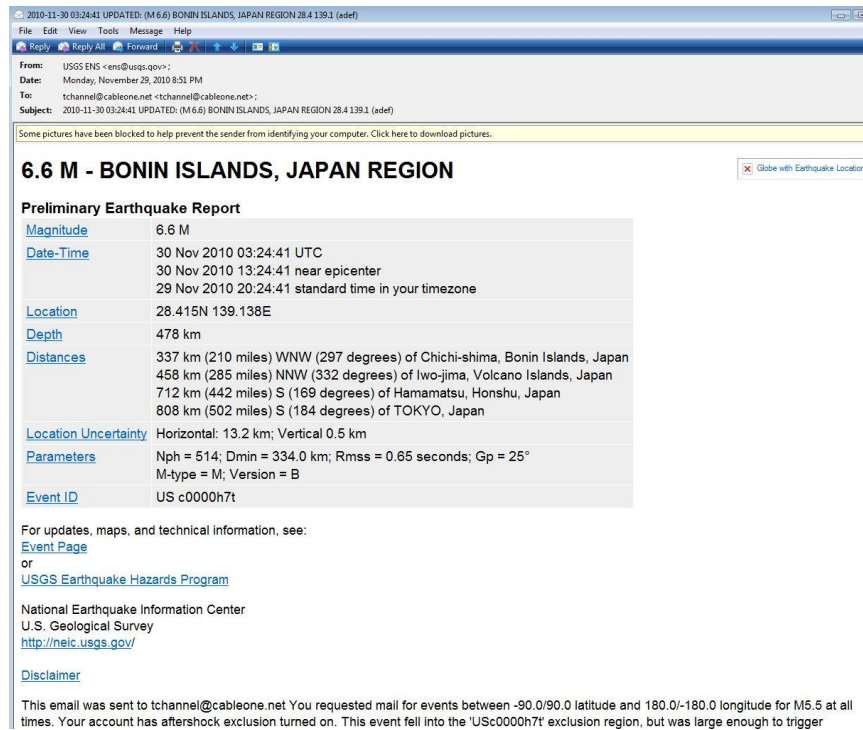
To receive USGS earthquake notifications, access the USGS Earthquake Hazards Program Website: <http://earthquake.usgs.gov/>

Select tab “Real time feed and notifications”

Select “Earthquake Notification service”. Subscribe. You will receive text or email messages notifying you of seismic events.

Go down to **Subscribe, Step 2**, and **Create your account**. You will be asked a series of questions about the parameters you want to set for receiving earthquake notifications. You can use any settings you want, but I use worldwide earthquakes (Default World), 24-hour notifications, and magnitudes 3.0 and greater for the U.S. and 5.0 and greater for worldwide. Skip through the information to **Managing Your Email Addresses**. Select HTML as message format, and 00:00 for day begins and day ends. **Save**. Skip to **Change my account preferences**. Select Yes for “Aftershock.” Select Yes for “Receive updates for events.” Select No for “Defer notifications during night hours.” After you set up your account, you will be notified of earthquakes by automatic email notices (fig. 1).





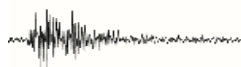
Example of USGS Notification.

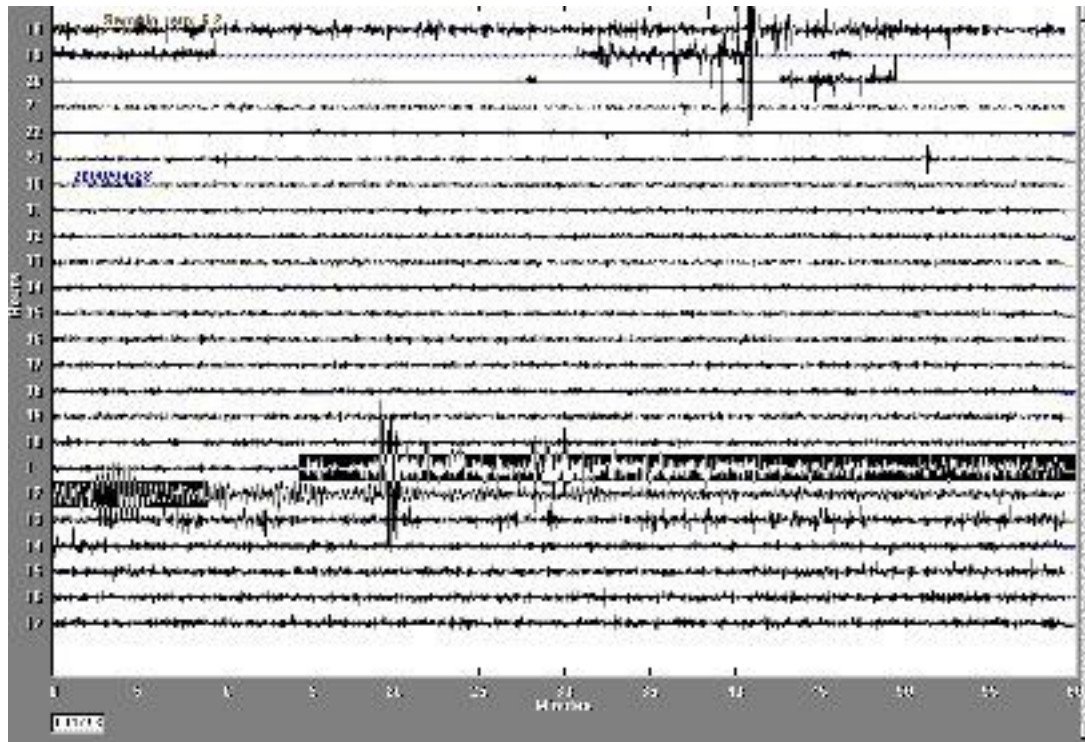
2) Process the Earthquake.

Processing will involve two software programs, AmaSeis and WinQuake. AmaSeis is the viewer and logger where the earthquake traces are recorded in 24-hour time (hereafter called the datalogger or datalogger screen), and WinQuake is used to edit, filter, print, and publish the earthquake data.

i. Extract the Earthquake using Amaseis

First you use the AmaSeis program. If the earthquake is recorded on the current datalogger screen, highlight the earthquake trace, using the event time on the USGS notification sheet as a guide (fig. 2).

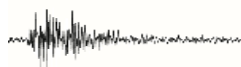




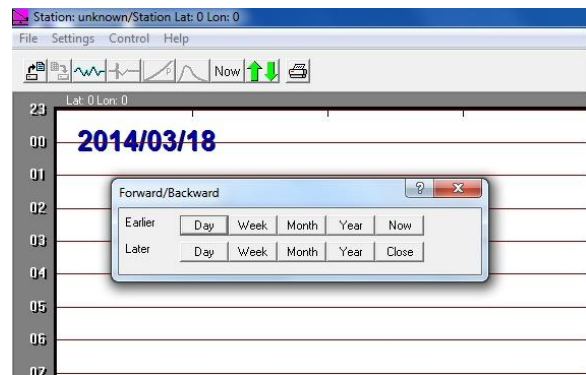
Highlighted earthquake trace on datalogger screen.

Where to start and end highlighting the trace is optional; however, you may find the following suggestions helpful:

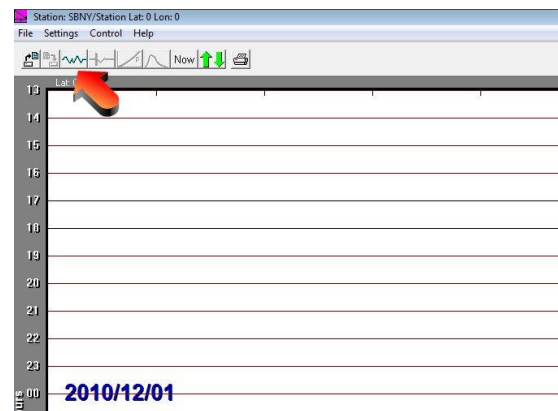
- Others may be comparing your data file with theirs, so some continuity in time lines is beneficial. If the event time is 11:43, for example, you might consider rounding to a better number, such as 11:30.
- For small earthquakes, the P wave should be more or less centered between the start and end of the trace. If the P wave occurred at about 11:30, then highlighting should start at 11:00 and end at 12:00. For large earthquakes with 2 or more hours of data, the P wave would be left of center, perhaps at 20 percent of the time line, because there would be a lot more data after the P.
- All earthquakes are different, but most will contain a 20-minute trace, a 30-minute trace, or up to 180 minutes or more. Leave blank space before and after the visible trace on the screen.



If the earthquake has been recorded earlier on a datalogger screen that is no longer visible, at the upper left on the computer toolbar, pull down the **Settings** menu. Click on **Date/Time**, highlight the month and day that are there and enter the month and day of the earthquake, using the USGS notification sheet. Click **OK**. AmaSeis also has two green arrows on the toolbar to scroll back to an earlier day, and a **Now** button to return to the current time (fig. 3).

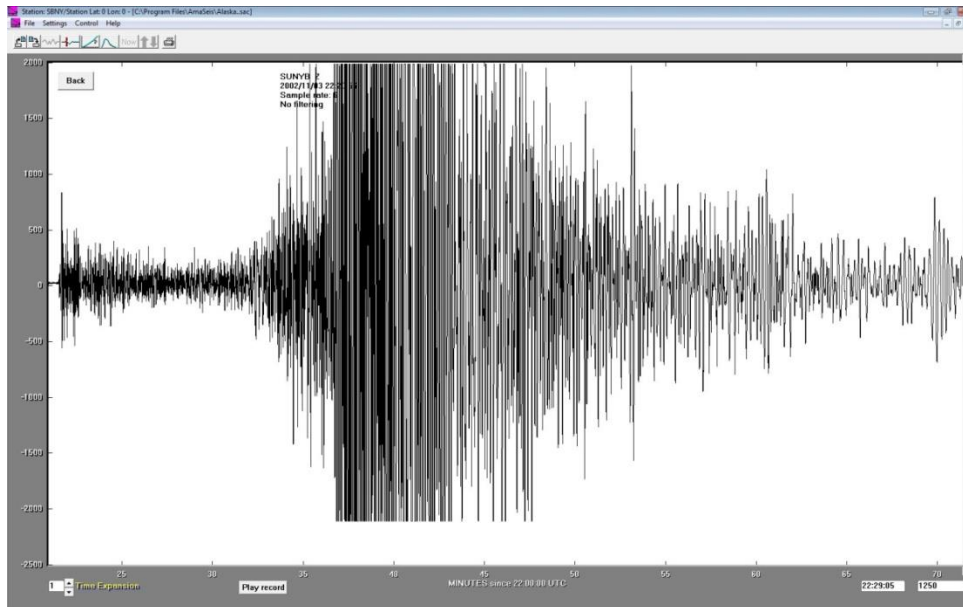


With the earthquake highlighted (shown in figure 2 in black), click on the “Extract earthquake” icon on the top toolbar (green squiggly line that looks like an earthquake trace)—see figure 3.



“Extract earthquake” icon.

The enlarged image will now appear in a different window as an enlarged image (fig. 4).



Enlarged image of extracted earthquake trace.

At the top left of the toolbar, pull down the **File** menu; click **Save As**. Save on Desktop. Name the file as follows, beginning with the year, month, and day (yymmdd); then the time (hours, minutes, and seconds); then the station name. Use a period between each set of identifiers, and use no spaces:

11 0 3 28 . 1 0 3 5 2 1 . B S U
(date) (time) (station name)

Save the file as a .PSN or .SAC file to the desktop.

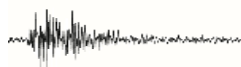
Click on **Back** at the top left of the enlarged earthquake screen (see in figure 4); this restores the AmaSeis datalogger screen. On the toolbar in the datalogger window, click **Now** to return the datalogger to the current day.

Minimize AmaSeis, the datalogger window (-). **Don't close (x).**

ii. Identify the earthquake using WinQuake

Now you can see the file you just saved on the desktop. Double click on this file to open it in WinQuake.

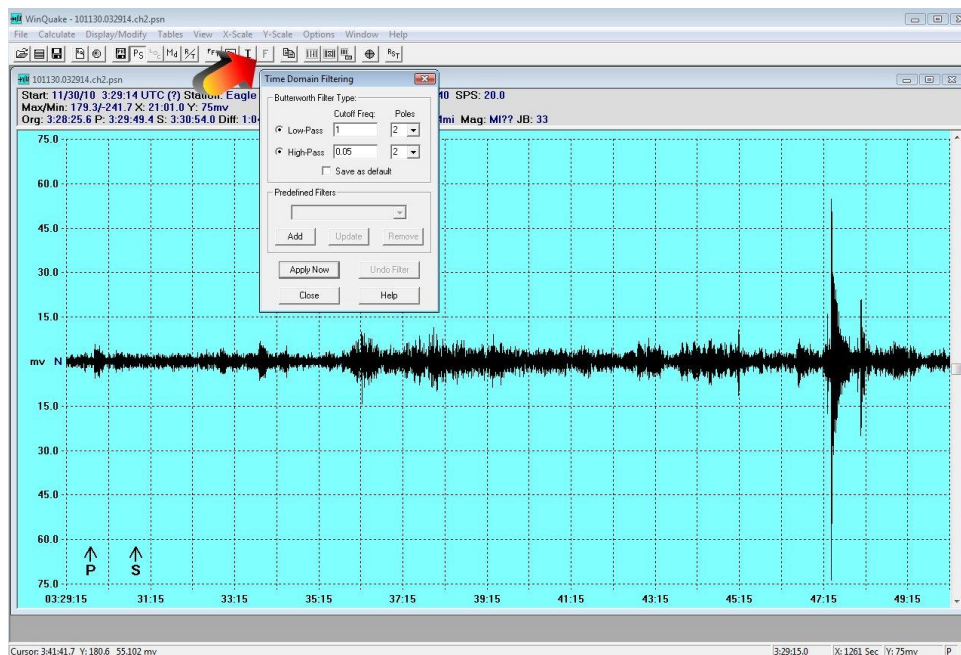
To process your data, you will need to filter it. Filtering is important because it removes undesired frequencies from the earthquake trace and enhances the desired frequencies. The undesired frequency, called noise, can be generated by traffic, students in the



classroom, even wind applying forces on the building that contains the seismometer. Click on the **F** icon on the top toolbar for filtering (fig. 5).

Depending on the type of earthquake you presume to have recorded, select the following:

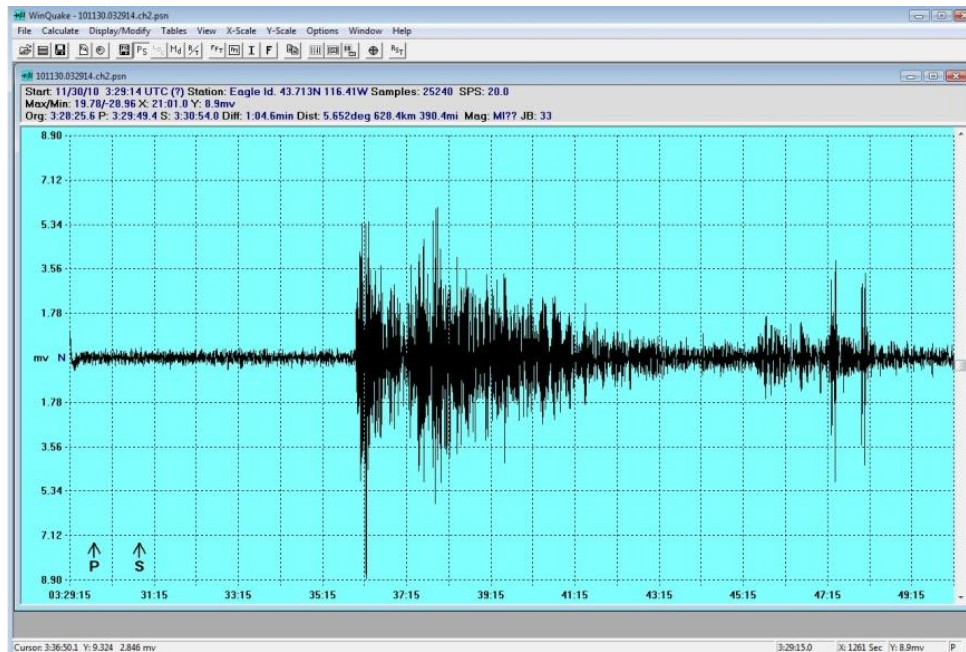
	High pass	Low pass	Poles
Local earthquake	0.5	1.5	2
Teleseismic event (>1000km from station)	0.5	1	2



Applying a filter to the earthquake trace.

The data file should now look better, as seen below





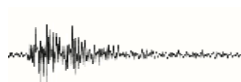
Earthquake trace after filtering.

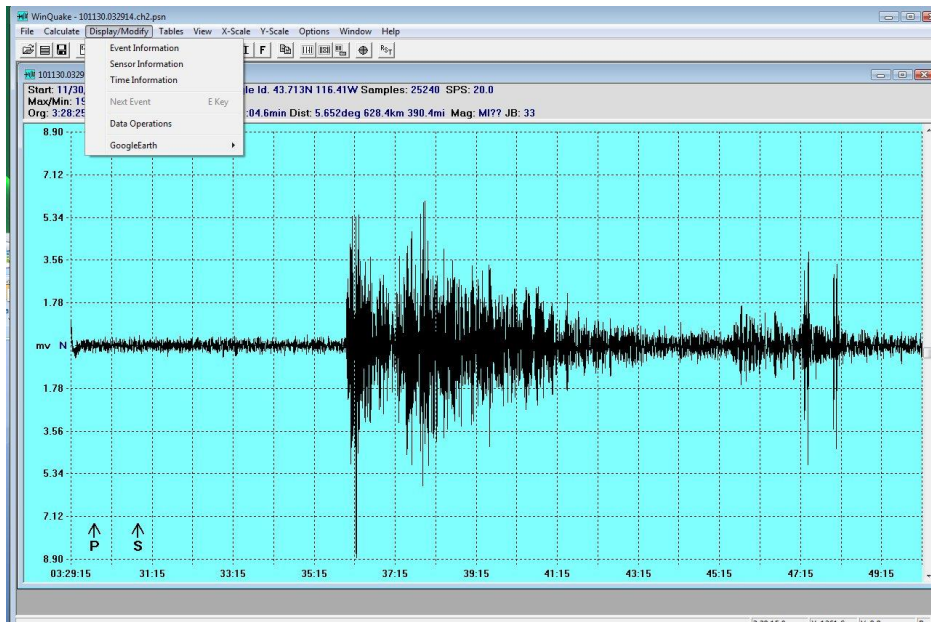
If you adjusted the time on the computer, you need to adjust the time on this earthquake display also, because the traces were recorded when the computer clock was running at an inaccurate time and, if not adjusted, will cause WinQuake to misplace the earthquake phase markers. If you adjusted the time on the computer, see instructions in Appendix A.

Now enter both your Sensor information and the Event information. Pull down the **Display/Modify** menu (fig. 7), click on **Sensor Information** and enter the latitude, longitude, and elevation of the station; then click on **Event Information** and enter your data.

You can find earthquake information on either:

- USGS website: <http://earthquake.usgs.gov/earthquakes/>
- IRIS Website: <http://www.iris.edu/seismon/>
- Geonet website for more local earthquakes: <http://www.geonet.org.nz/>





Display/Modify menu.

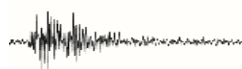
You need to enter your Sensor information only once. WinQuake will save your Sensor information.

For the Event information, in the Comment box, enter the information as given on the USGS notification sheet. Use the format:

M7.5 xxx km from BSU1 Taupo ID – NAME OF EARTHQUAKE

- Enter the time of the earthquake (for example, 11/30/2010 05:56:59)
- Enter the magnitude in the Mw box.
- Enter the latitude and longitude of the earthquake. Ensure that the latitude ends with the letter N (north) or S (south), and that the longitude ends with the letter E (east) or W (west). Another way of entering these coordinates is:
 - enter a plus (+) in front of the latitude number, indicating North latitude, or a minus (-) indicating South latitude;
 - enter a + in front of the longitude number, indicating East longitude, or a -, indicating West longitude. Taupo is -38.7 or 38.7S latitude, and +176.0 or 176.0E longitude.
- Enter the depth of the earthquake.

At the bottom of the window, click **OK**. The P and S and any other phase markers you may have specified should now be show (fig. 8). Other information, such as arrival times, distances, etc., also has been automatically entered.

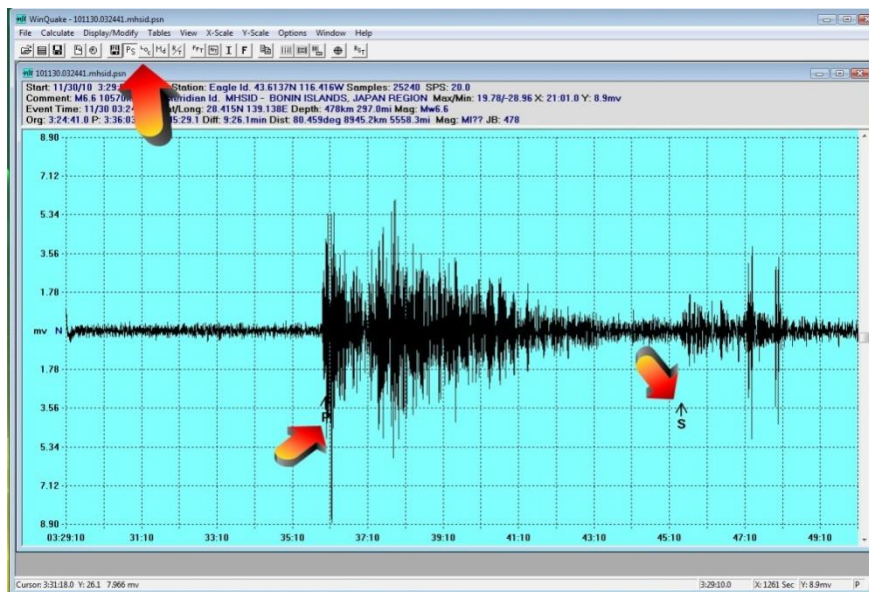


If the predicted arrival time of the P-waves fit your recorded P waves, you have identified the trace correctly!



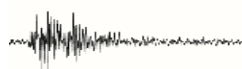
Pull down the **Display/Modify** menu again and left click on **Event Information** again. Highlight the “xxx” in the Comment box and enter the correct number of kilometers, which has automatically been entered in the descriptive information at the top of the earthquake image.

More on the phase markers: If desired, click on **View/Phases/Display**. You can select the different phases you want displayed on the earthquake image. If you want to print the earthquake image with these phases marked, **Save** and overwrite the old file.

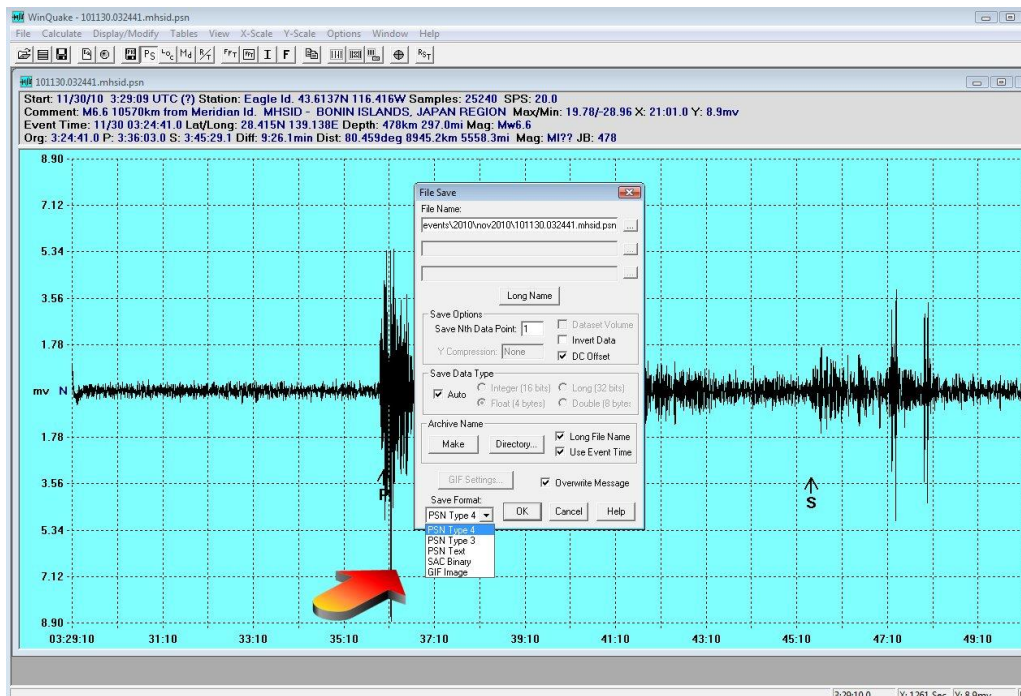


WinQuake automatically adds phase markers when the Event Information is completed.

When you are satisfied with the final earthquake image, pull down the **File** menu and **Print** a copy if you wish. You can also use the Google Earth feature to fly from the event to your station.



After printing is done, the completed earthquake image can be saved in two formats for posting—(1) PSN Type 4 or SAC Binary, and (2) GIF. Pull down the **File** menu and click **Save**. Under **Save Format**, click on PSN Type 4 or SAC Binary (bottom of File Save window). Click **OK** (fig. 9).



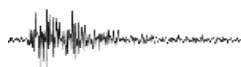
Save the completed earthquake image as PSN or SAC, and GIF.

Pull down the **File** menu again and click **Save**. Under **Save Format**, click on GIF Image. Click **OK**. Close WinQuake (x).

If you save your file as an SAC binary, additional steps may be required. See Appendix A.

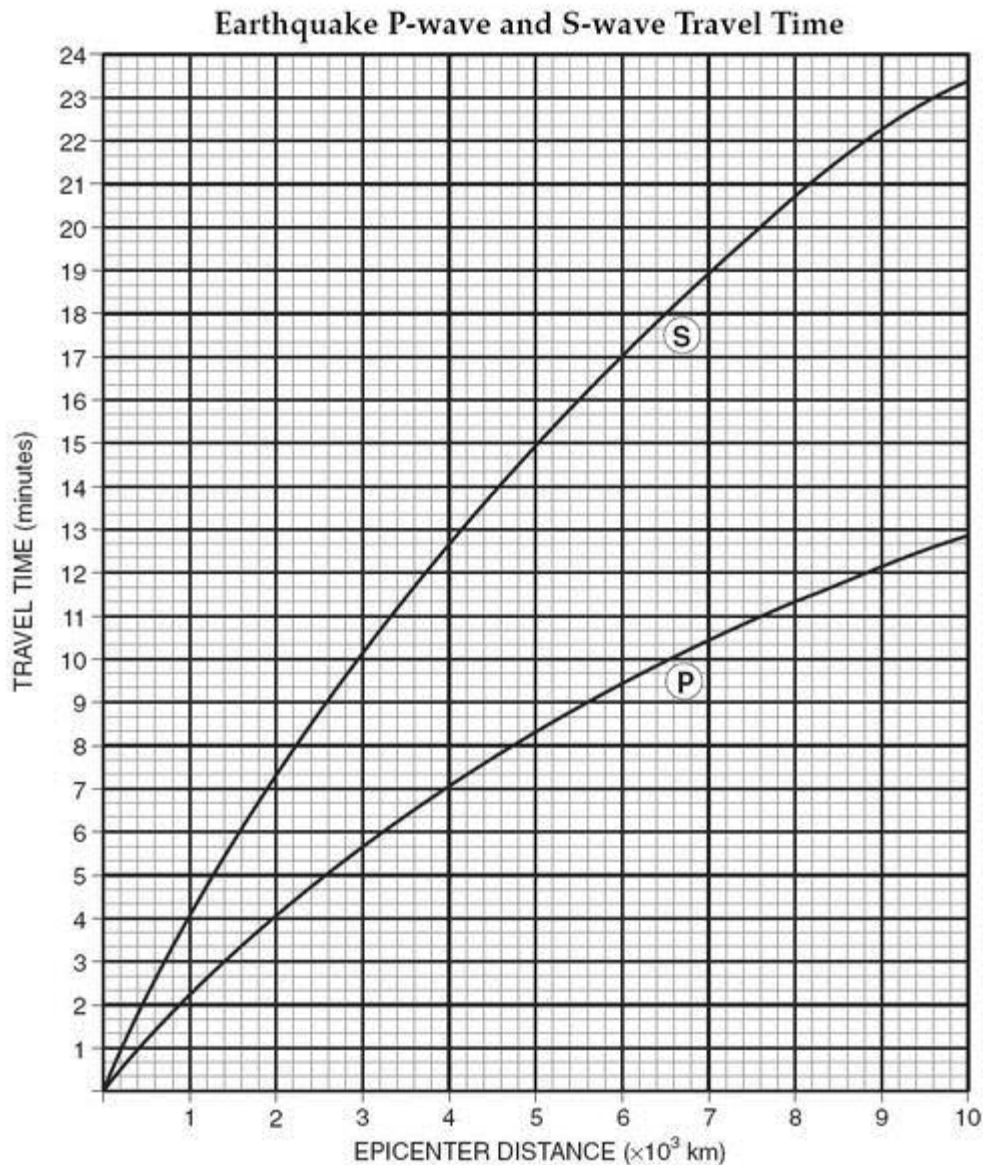
Step 4. Networking with other schools using IRIS: some real seismology!

WinQuake is an ideal program to help you identify which earthquake you have recorded. However, seismologists cannot extract much information using a single station.



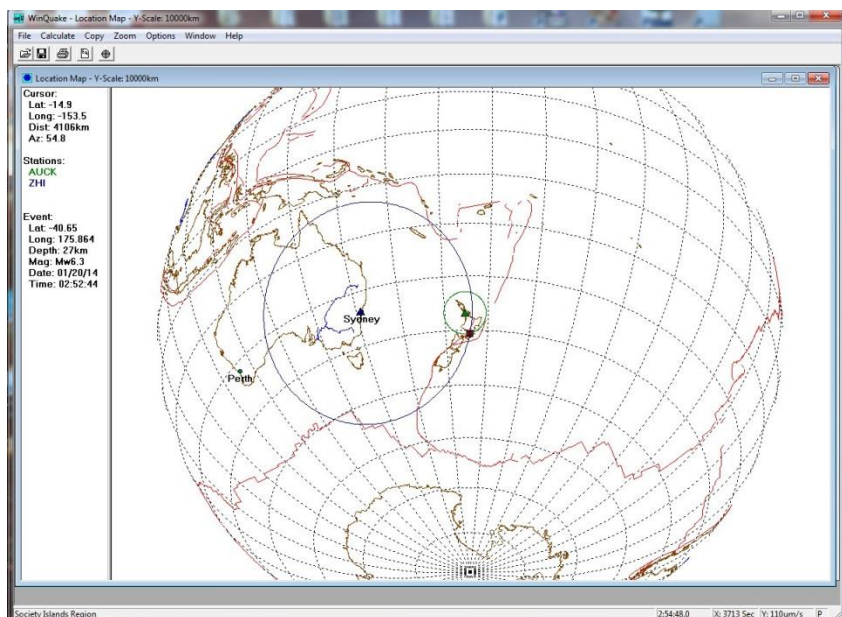
With your station, knowing the time interval between the P wave arrival and S wave arrival, you can evaluate the epicenter distance at which these waves were emitted using the graph below (from

http://edition.cnn.com/fyi/interactive/0006/riverdeep/earthquakes/earthquake_tips_a.html).



WinQuake allows you to measure such a time difference and from the equivalent epicenter distance, you could plot manually on a map a circle corresponding to the distance or use WinQuake directly using the tab “View/Locate Event”.





Using the data from 2 stations, you can narrow down the position of the epicenter to 2 locations, i.e., the intercept of the 2 circles. Using the data from 3 stations will narrow down the choice to one location only, the real epicenter of the earthquake. This is the reason behind the necessary networking in seismology.

Iris (Incorporated Research Institutions for Seismology) provides a free platform for such a necessary exchange of information. To network with other schools, you need to register your station at <http://www.iris.edu/hq/ssn/schools/register>



IRIS
Incorporated Research Institutions for Seismology

SEISMOGRAPHS
in schools

IRIS Home E&O Home



Sponsored by the National Science Foundation

Home
Seismic Data
Stations
Resources
Community
Contact

Register Your Station

After registering your station you will be able to upload your recorded seismic data and share it with other stations.

Privacy Policy

Any information you enter will be solely used by the international educational seismology community. It will not be distributed to any 3rd parties. This information will only be used to contact you if there are problems with your application. Additionally, we may contact you with tips and information about operating your station.

School Info

Bold fields with a * are required



If not all the lines fit on the square, it most likely means that the computer time of one of the recording stations is inaccurate and needs correction.

To get a different perspective, you can get the globe to rotate by double clicking on the green dot located next to big cities.

Don't forget to try the Google Earth option in Winquake, and fly your students and yourself from your station to the event! Explore and Enjoy!!

Step 5. Problems? Help is at hand.

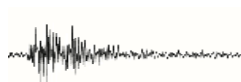
For questions please contact:

Ted Channel : tchannel@cableone.net

Dr Kasper Van Wijk: k.vanwijk@auckland.ac.nz

Dr Caroline Neuberg: caroline.choux@gmail.com

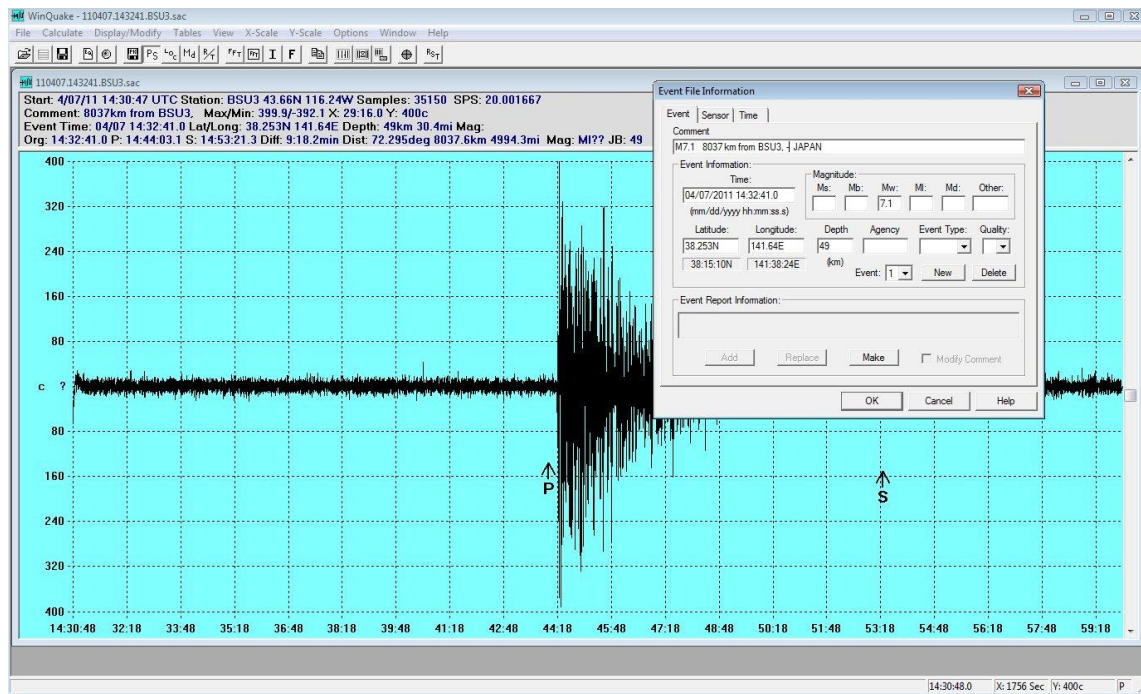
More information can be found at: <http://cgiss.boisestate.edu/ssis> or
<http://tc1seismometer.wordpress.com>



Appendix A. Saving SAC Binary File; Time Correction

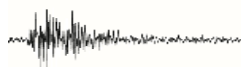
If you save your file as an SAC binary, additional steps may be required:

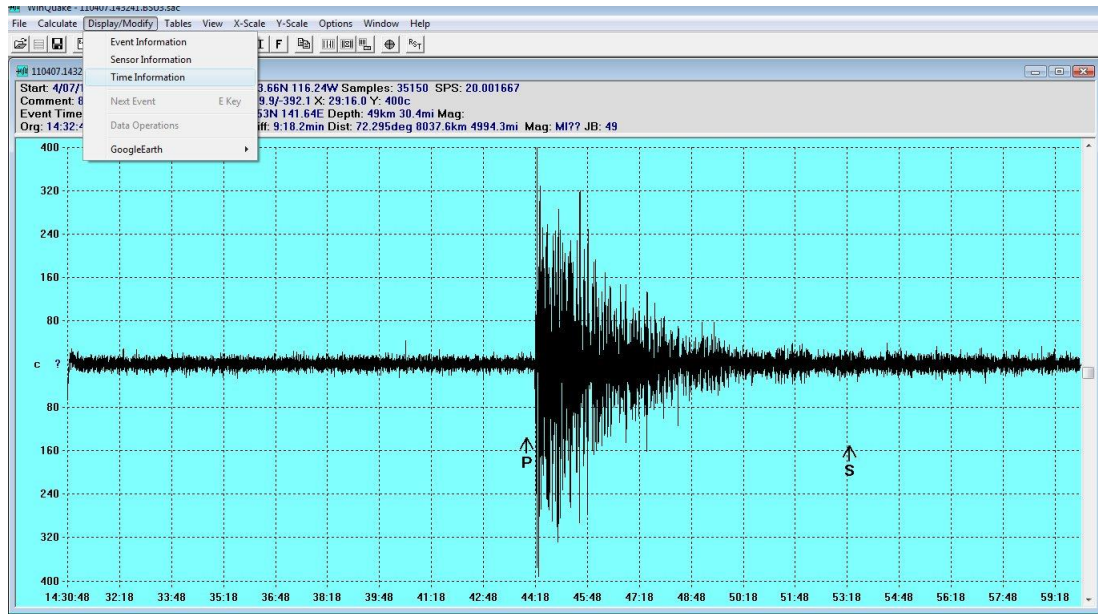
- Make sure the Sensor and Event information have been entered, and click **OK**.



Event File Information window.

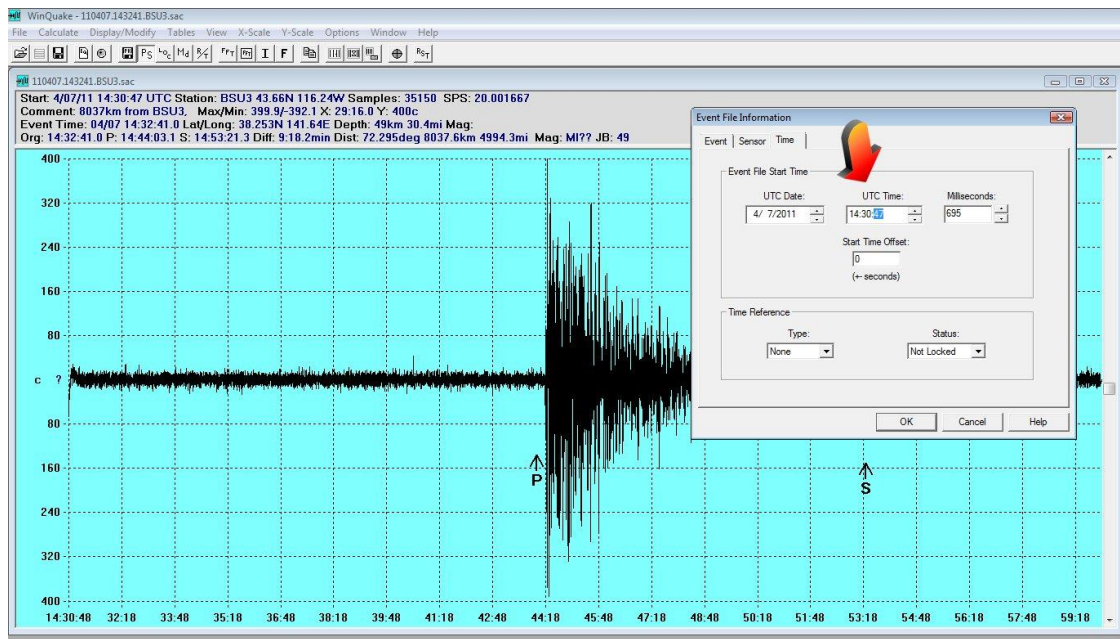
- Pull down the **Display/Modify** menu; click on **Time Information**. In the **Event File Start Time** window, adjust the time according to the correction you noted when you corrected the computer clock. If, for example, the computer clock was 9 seconds fast, enter -00:00:09 in the **UTC Time** window. This subtracts no hour, no minutes, and 9 seconds from the earthquake trace. If you wanted to save as a PSN file you could enter -9 in the **Start Time Offset** window but, for an SAC file, enter the correction in the **UTC Time** window. Click **OK**. (If you need to add increments of time, do not enter a minus sign.)





Time Information menu.

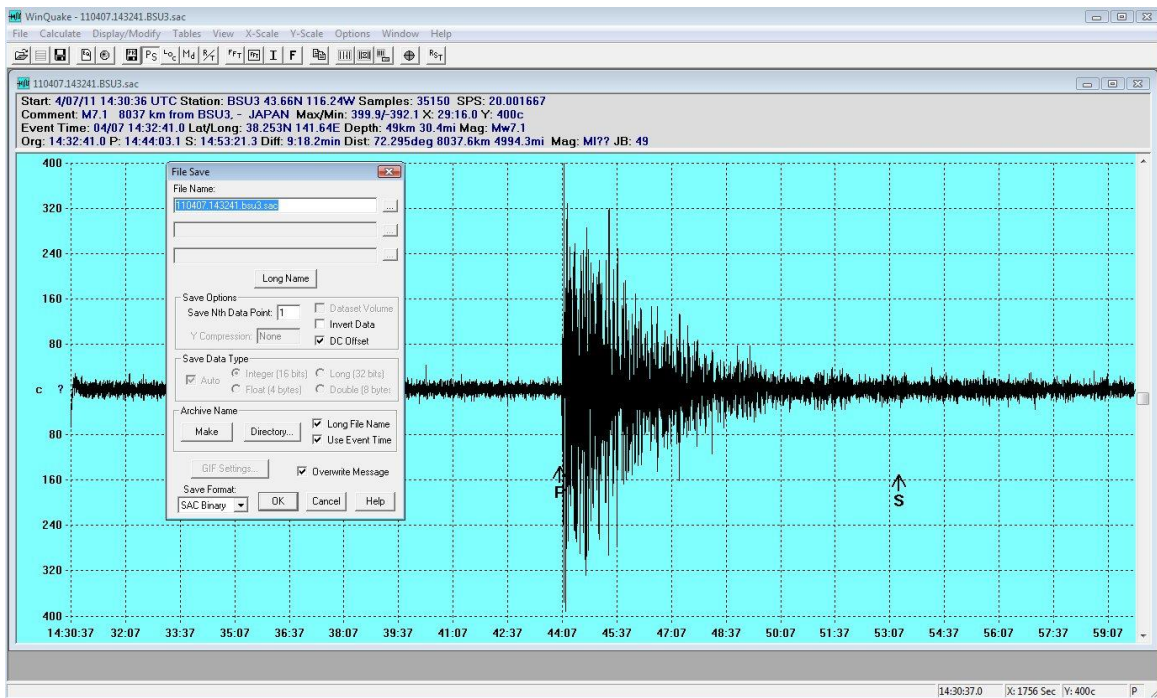
- Pull down the **File** menu and **Save**. If you do not do this step, when you close, the Event Information will be removed.



Applying a time correction in the UTC Time window.



That should move the P and S phase markers to their correct positions. Then pull down the **File** menu and **Save as** SAC binary (fig. 13). Now when the SAC file is closed and reopened, the changes should be saved and the P and S markers located correctly.



File saved as SAC Binary.

This software situation should be corrected in the newer versions of WinQuake.



Appendix B.

Teaching Geophysics with a Vertical-Component Seismometer

Kasper van Wijk, University of Auckland, Auckland, New Zealand

Ted Channel and Karen Viskupic, Boise State University, Boise, ID

Martin L. Smith, Blindgoat Geophysics, Sharon, VT

Earthquakes are some of the more dramatic expressions of the dynamics of our planet. The sudden release of stress built up slowly by tectonic or volcanic processes often has far-reaching consequences, and can be measured (in classrooms) around the world. This is one reason why designing and building seismometers has been a popular activity,^{1,2} and why different versions of “Seismometer in Schools” projects thrive in the United States, Australia, and Europe. We present a cheap, robust, and easy-to-build seismometer—called the TC1—to measure seismic displacements in the vertical direction. Its components are easy to obtain and assemble, yet the resulting instrument is accurate enough to record earthquakes from around the globe. The parts list and building instructions of the TC1 seismometer are freely available online. Alternatively, a complete kit can be purchased for around US\$300. Assembling the system naturally introduces students to a number of concepts in physics and engineering, while upon completion seismic recordings trigger discussions about the dynamics and internal structure of the Earth. The discussions are fostered by service learning and shared in the network of TC1s called the Z-NET.

The TC1 seismometer

The following describes in broad strokes the components of the TC1. Detailed instructions, including the Bill of Materials, on how to build a TC1 seismometer are available online at <http://tc1seismometer.wordpress.com/>.

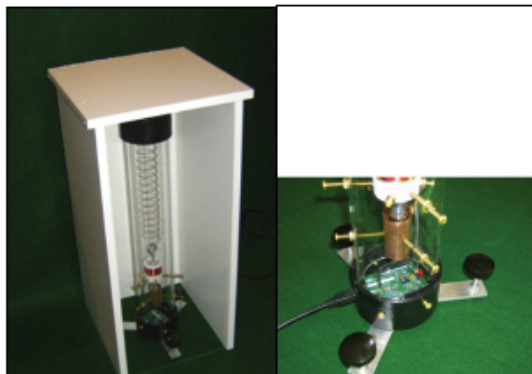


Fig. 1. Left: Photograph of the TC1 seismometer, based on a magnet and Slinky toy spring. Right: a close-up of the bottom of the induction coil, the damping system of a magnet inside a copper tube, and the NERdaq recording system.

• Spring, mass, coil, and magnet

At the heart of the TC1 seismometer is a harmonic oscillator composed of a mass on a spring, inside a clear-plastic frame with legs (Fig. 1). Ground motion moves the frame, but the inert mass resists movement. Our spring is a Slinky® toy with a natural period around 1 s, and the mass is a neodymium magnet. The magnet is positioned inside a handmade coil consisting of many wraps of narrow-gauge copper wire and which is attached to the frame. When the frame is disturbed by ground motion, the magnet on the spring moves relative to the coil, which leads to an induced current in the coil.

• Magnetic damping

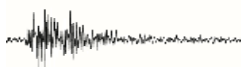
To isolate seismic vibrations from the ringing of an excited harmonic oscillator, we damp the system. Historically, seismometers were damped using friction from a viscous fluid (such as oil), but here we use magnetic damping with a second magnet suspended well below the first magnet on the spring. This second magnet is positioned inside an isolated copper tube, attached to the frame. When the sensor is perturbed, the second magnet induces eddy currents in the copper tube that counter-act the motion of the spring/mass.

The digital acquisition system

Like all modern seismometers, the TC1 uses a wide dynamic range digital recording system. Our system is named the NERdaq. We have constructed a simple system consisting of an analog stage with an integral high-cut filter followed by a 10-bit analog-to-digital converter (ADC) that is heavily oversampled. Oversampling is simply the technique of heavily averaging a noisy stream of digital samples to produce a slower stream with greater effective resolution.³ Figure 2 is a graphical representation of the steps that make up the NERdaq.

The analog side of the system consists of an op-amp that provides a gain of about 800 together with a simple high-cut filter that starts to roll off at about 2 kHz. This unusually high cut-off frequency provides noise to the ADC input that makes oversampling work.

The digital side is based upon the popular, inexpensive open-source Arduino hardware, in our particular case the Arduino Uno. This system supports 10-bit ADC conversion at 9600 samples per second (sps). We use an averaging window of 2048 samples, which is stepped by 512 samples to provide an output sample rate of 18.78 sps. This heavily averaged output has an effective resolution of about 16 bits (although system noise uses up one or two bits of resolution). The data



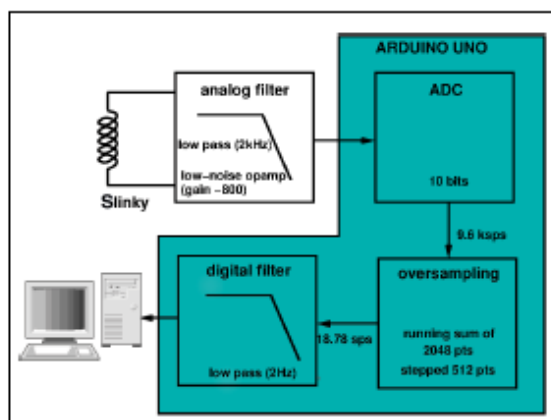


Fig. 2. Block diagram of the NERdaq interface between the raw analog signal and computer.

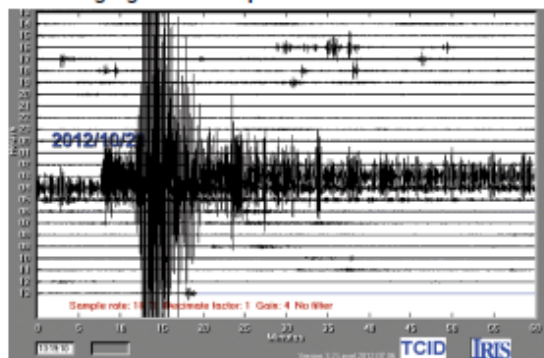


Fig. 3. Snapshot of the seismic data recorded on station TCID in Eagle, ID, on Oct. 28, 2012, when an earthquake struck off the west coast of Canada at 03:04:08 UTC.

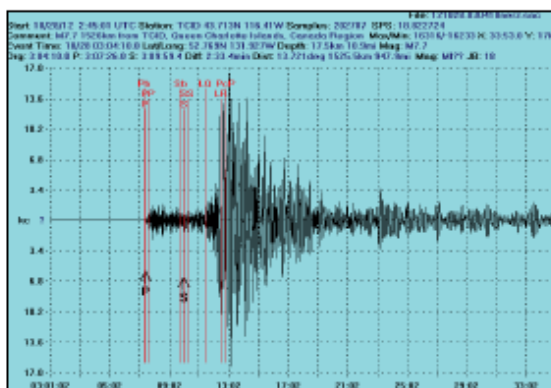


Fig. 4. Part of the seismic data from Fig. 3 that contains the signal from an earthquake located off the west coast of Canada. The different seismic waves arriving in Idaho have been annotated.

stream is then subject, in software, to three digital filters:

- 1) a low-pass minimum-phase filter at about 2 Hz to reduce noise,
- 2) a band-boost filter that enhances the signal between 10 and 20 s to highlight short-period surface waves, and
- 3) a high-pass filter with a 30-s cutoff to remove drift.

The first filter introduces an impulse delay of about 0.4 s, which we judged tolerable. The other filters have little effect on the high-frequency P-wave arrival.

The system is implemented on a printed-circuit daughterboard that couples directly to the Arduino Uno (although the analog part is simple enough to wire by hand). The latest version of the TC1 has the NERdaq built into the bottom part of the sensor case, with its output fed via USB to the host computer.

• Amaseis

Once signals are filtered and converted from analog to digital in the NERdaq, we display the seismogram on a PC with software named Amaseis, written by Alan Jones for the IRIS “Seismometers in Schools” program.^{4,5} While originally written for the AS-1 vertical seismometer and its “black box” interface, the TC1 system seamlessly operates with Amaseis. On the same computer, timing accuracy is ensured with a free version of software called AboutTime.⁶

Classroom seismology

Once the TC1 is completed, exciting seismic records such as in Fig. 3 are quite common. These are a starting point for inquiries in a number of concepts in seismology, supporting lessons about the Earth’s subsurface structure and processes. We encourage the students to enroll for an automated warning system such as the one run by the United States Geological Survey (USGS), so that students are notified when significant earthquakes have occurred.

• Earthquake identification

When students observe an anomalous signal on their sensor, an email or text message from the USGS can confirm (or deny, if this was a “bump” of the instrument) the recording is from an earthquake. Figure 4 shows the data that contain the main energy recorded from an earthquake with magnitude 7.8 off the west coast of Canada from Oct. 28, 2012, at 03:04:08 UTC. Annotated are the *predicted* main arrivals of different seismic waves, based on a spherically symmetric model of the Earth.⁷ We used Larry Cochran’s Winquake software, but (freeware) alternatives with similar capabilities, such as Obspy and Amaseis, are available. Most obvious is the prediction and the onset in the data of the fastest seismic wave (the primary or P-wave is marked with a single “P”) followed by the slower secondary or S-wave, and seismic waves that bounce off the surface and main interfaces of the Earth (core, mantle, crust). Seismic waves that travel along the Earth’s surface (so-called Rayleigh, LR, and Love waves, LQ) make their way from Canada to the TC1 station in Idaho as slower, but more energetic, signals. The predicted seismic phases overall match the data, which means that the approximation of a spherically symmetric Earth structure is not bad at all. In fact, it is the small deviations from this approximation that seismologists use in seismic tomography to unravel the details of the Earth’s subsurface structure.⁸

• Finding the epicenter with the TC1 network

To estimate the epicenter of an earthquake, schools can first compare the arrival of the P-wave at various stations. The earlier the arriving P-wave, the closer a station is to the epicenter. While this can provide a first-order estimate with a large network, students can then try to identify arrival of the secondary wave (S-wave). The time difference between the S- and P-wave (S-P) from an earthquake recorded at a specific station determines the distance from that station to the epicenter (Fig. 5). Students can then draw a circle with a radius that equals this S-P distance on a map. The earthquake could lie anywhere on this circle, but similar epicentral distance circles from two more TC1 schools uniquely define the epicenter.

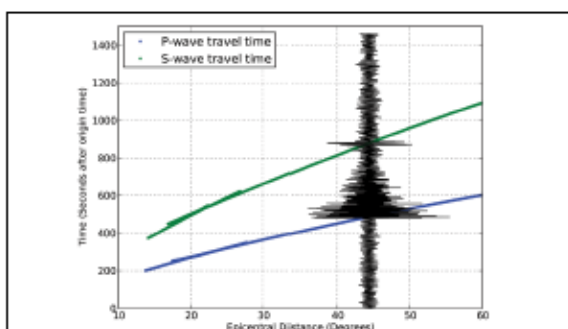


Fig. 5. Seismogram with predicted P- and S-wave arrival times in blue and green, respectively. This is overlaid onto a P- and S-wave travel-time plot for epicenters from 0 to 60°. At 43°, the S - P-wave travel time matches the curves.

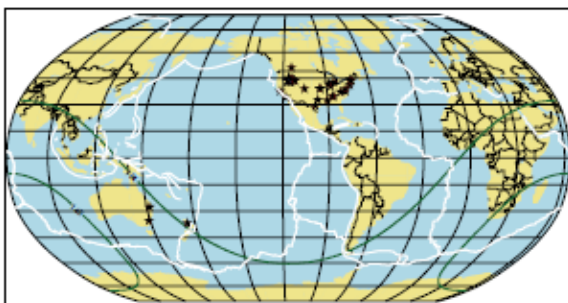


Fig. 6. World map with the members of the Z-NET indicated by stars. The 104° and 145° contours outline the P-wave shadow zone for station TCID (blue star). Because of the drop in P-wave speed in the liquid outer core, TCID does not record direct P-waves from this region.

• Service Learning and the Z-NET

Student engagement through hands-on learning is a productive learning strategy that integrates well with service learning: the promotion of student learning through relevant community service. In this case, students learn seismology by building a seismometer, helping a K-12 teacher set it up in his or her classroom, and then teaching K-12 students about the subject matter. As a result, undergraduate students have been mentors for institutions of secondary education. Now,

some 50 TC1s populate the planet in our network called the Z-NET (pronounced "zed-net," Fig. 6). If the TC1 user marks each epicenter of the earthquakes it records on this map, it will not be long until tectonic plate boundaries are outlined by these marks.

Conclusions

The robust TC1 seismometer, easy to build and understand, acts as a gateway to learning the underlying physics of the sensor. Topics such as inertia, (damped) harmonic oscillators, induction, and eddy currents pass in review in the assembly phase. Upon completion, the end-product of earthquake recordings sparks discussions about the physics of the Earth, including plate tectonics, structure of the deep Earth, and geohazards.

Acknowledgments

We thank all the students who helped build and teach with the TC1. The IRIS consortium generously hosts snapshots of seismic records of the Z-NET, while Chris Knudsen from New England Research, Inc. helped design the NERdaq. Larry Cochrane provided us with Winquake. Kara Ferguson and the service learning team at Boise State University were instrumental in integrating the TC1 in the classroom. KyW acknowledges NSF's support through award EAR-1142154. Last but not least, we thank Linda Channel, for it was her enthusiasm that started our journey to build seismographs, but her ongoing support makes this project a real pleasure.

References

1. J. Walker, "How to build a simple seismograph to record earthquake waves at home," *Sci. Am.* **241**, 152-161 (1979).
2. G. E. Averill, "Build your own seismograph: An earth-shaking, in-class project," *Sci. Teach.* **62** (3), 48-52 (March 1995).
3. F. Scherbaum, *Of Poles and Zeros: Fundamentals of Digital Seismology*, Vol. 15 (Springer, 2007), Sec. 6.2.2.
4. Alan L. Jones, Lawrence W. Braille, and Sheryl J. Braille, "A suite of educational computer programs for seismology," *Seismol. Res. Lett.* **74** (5), 605-617 (Sept./Oct. 2003).
5. Thomas J. Owens, R. F. Mereu, Alan L. Jones, H. Philip Crotwell, and Mitch Withers, "Of drums and needles...disappearing icons of seismology?" *Seismol. Res. Lett.* **74** (1), 44-47 (Jan./Feb. 2003).
6. <http://www.arachnoid.com/abouttime/index.html>
7. S. H. Jeffreys and K. E. Bullen, *Seismological Tables* (Office of the British Association, 1958).
8. See, for example, G. Nolet, "Seismic wave propagation and seismic tomography," in *Seismic Tomography* (1987), p 1-23.

University of Auckland, Auckland, New Zealand;
k.vanwijk@auckland.ac.nz

